Towards Improved Cloud Phase Retrievals Using Both MODIS and AIRS

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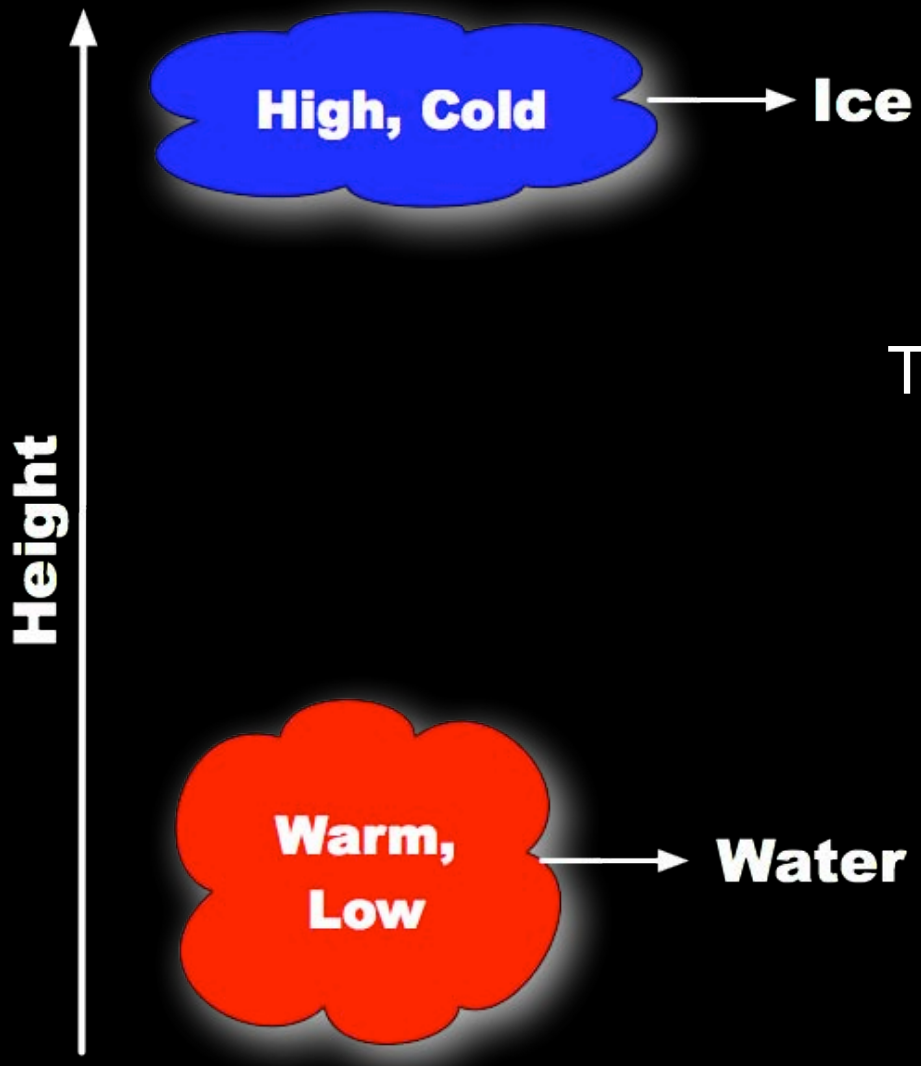
Motivation

- Retrieval of thermodynamic phase is important for:

1. Understanding how ice and water are distributed in the atmosphere
   - Horizontal, vertical, and temporal distribution
   - *Comparison to climate and regional scale models*
2. Further retrieval of cloud properties such as particle size and optical thickness

In a Perfect World



There would be no ambiguity.
Ice cloud T < 240 K
Water cloud T > 270 K

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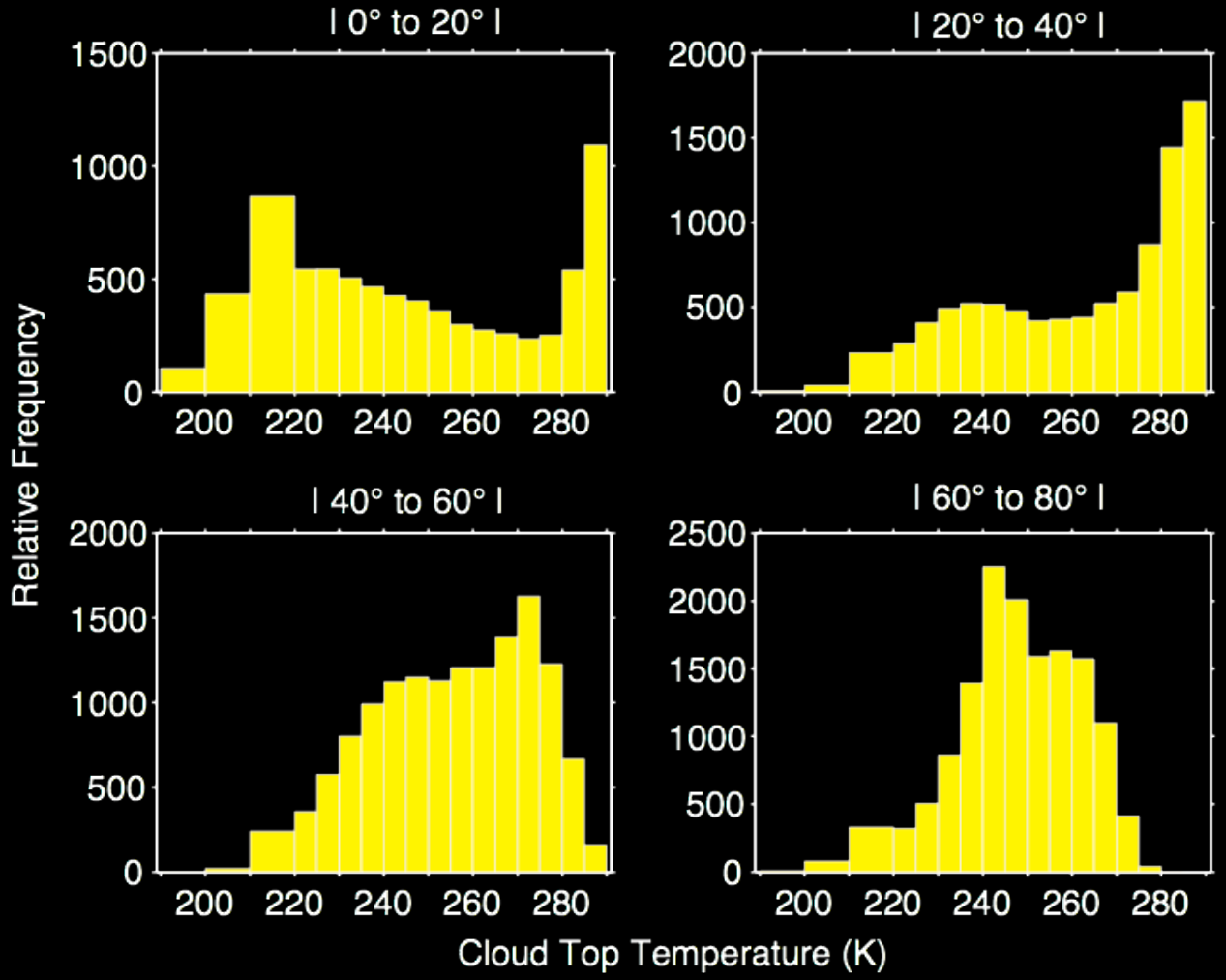
Cloud Top Temperature from MODIS

Zonally averaged (both hemispheres) MODIS Level 3 CTT, Jan. 2005



mostly warm clouds and cold clouds

A lot of in-between clouds

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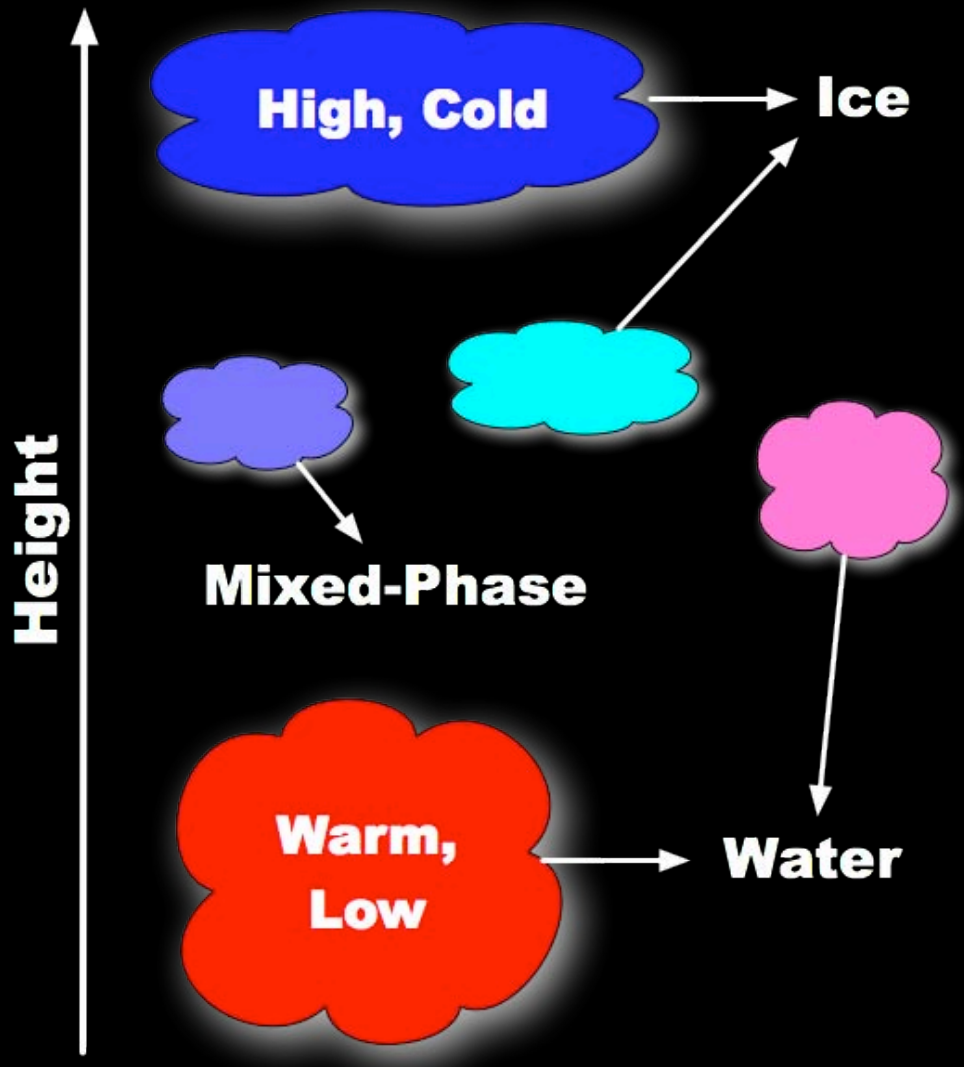
Reality - the cartoon version



Clouds between 250 and 265 K do exist and can be composed of:

- ice crystals
- supercooled water droplets
- a mixture of ice and water

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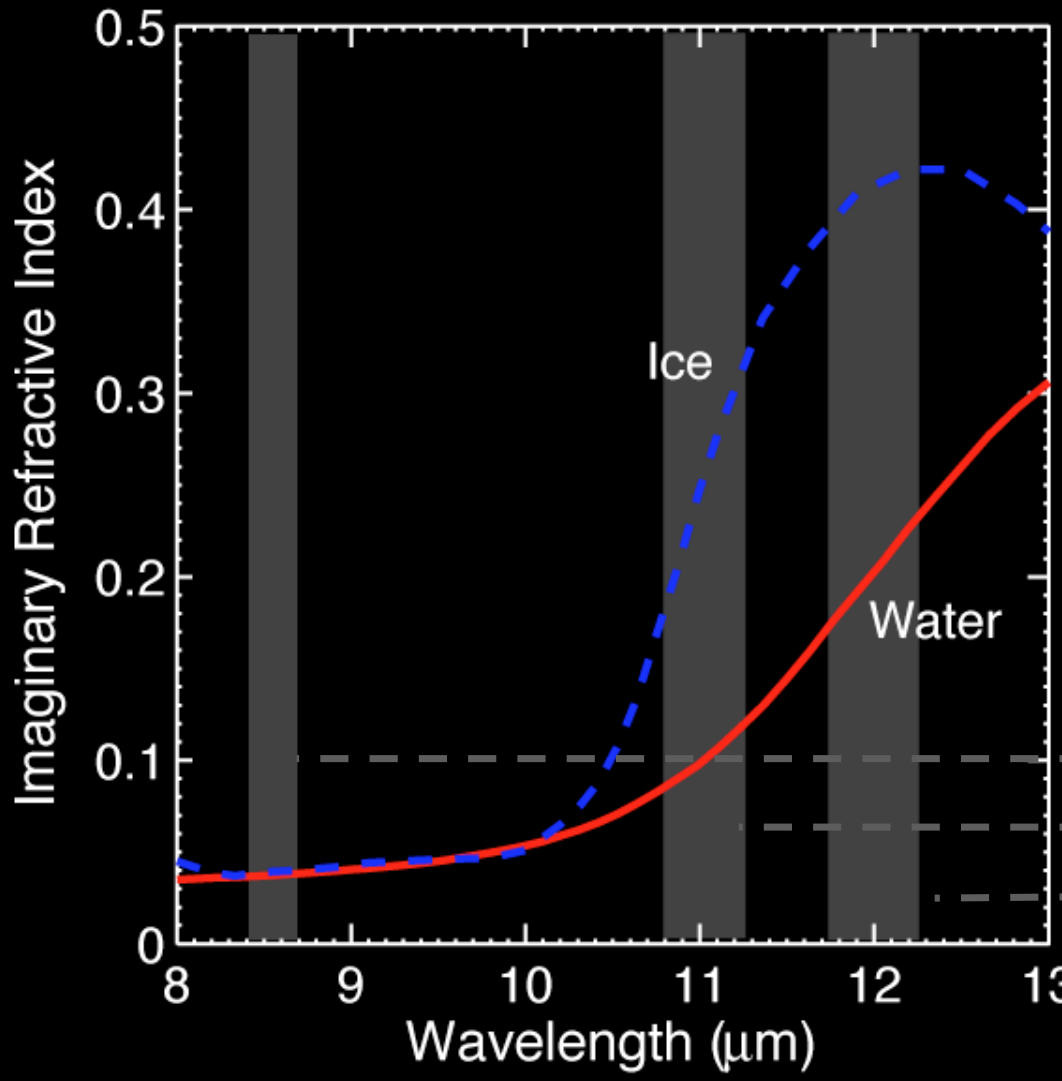
Application to MODIS Data

- MODIS IR phase algorithm is bispectral
  - 8.5 - 11 μm, 11 μm brightness temp.
- Phase classes are:
  - Water
  - Ice
  - Mixed and Unknown

Theory of Spectral Phase Discrimination



The spectral variation of the imaginary part of the index of refraction differs between ice and water

→ MODIS band 29 (8.5 μm)
→ MODIS band 31 (11 μm)
→ MODIS band 32 (12 μm)

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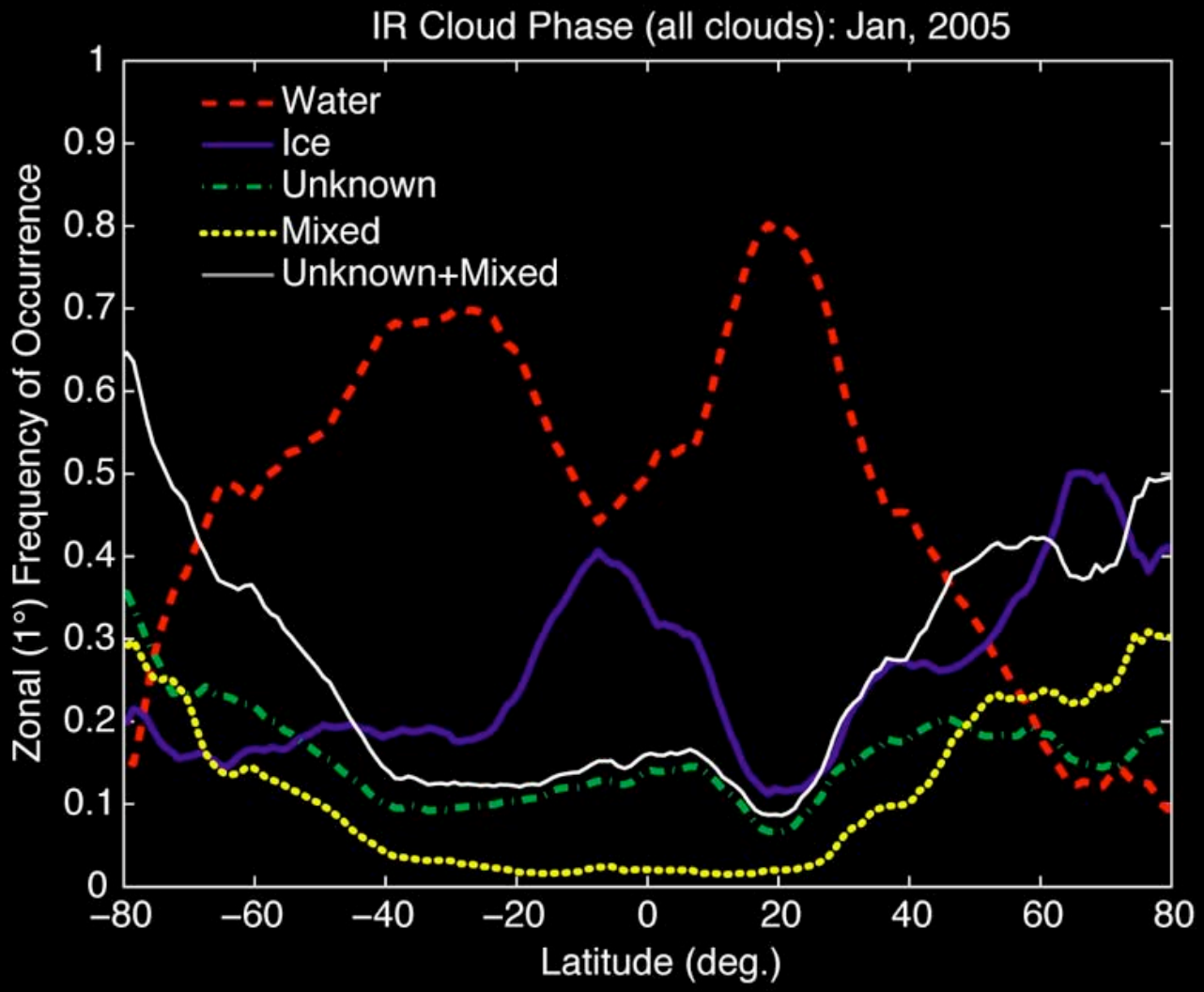
Application to MODIS Data (January 2005)



Near-global area-weighted averages
water: 51.5%
ice: 25.5%
unknown: 14.4%
mixed: 8.5%

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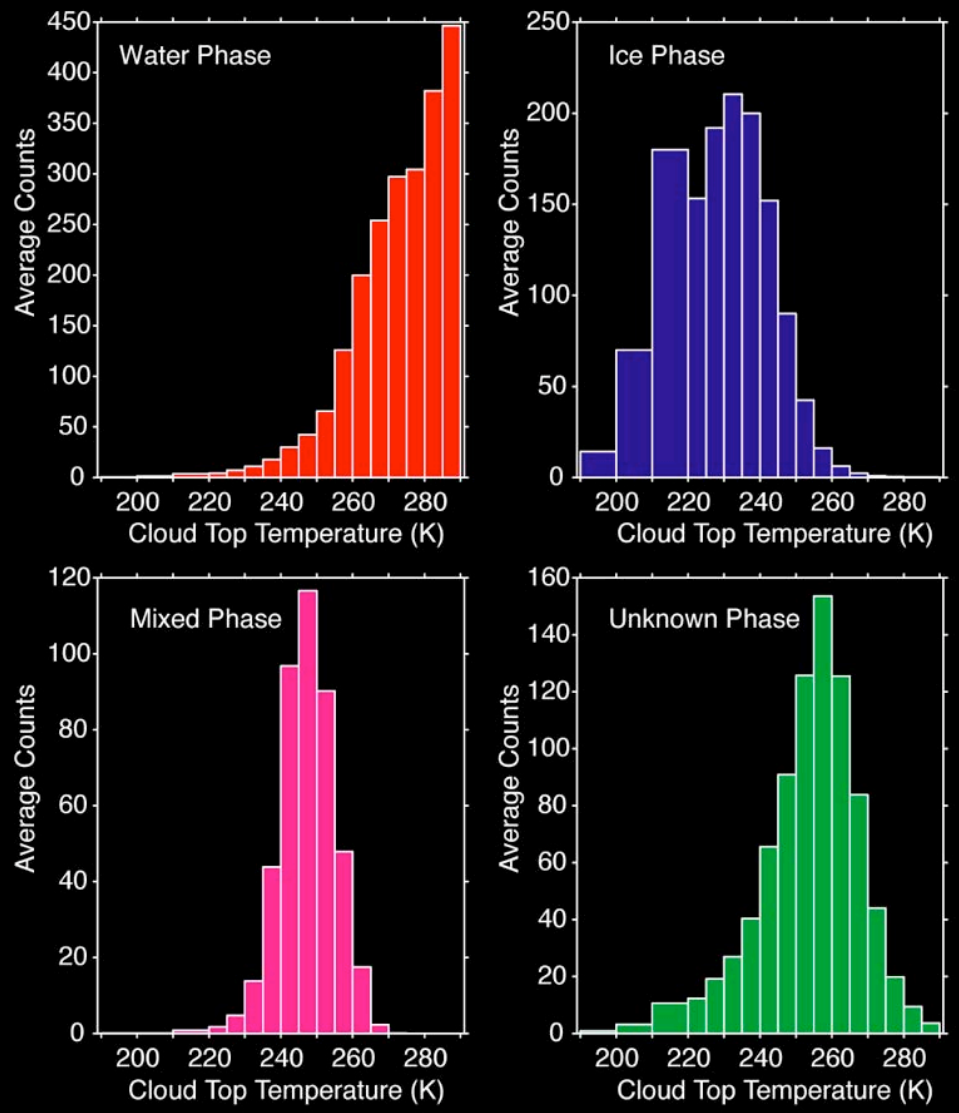
Cloud Top Temperature and Cloud Phase



Strong relationship between retrieved cloud phase (IR) and retrieved cloud top temperature from MODIS.

for 255 ≤ CTT ≤ 265 K
47% water
3% ice
9% mixed
40% unknown

Near global MODIS Level 3 CTT and IR cloud phase, Jan. 2005

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Radiative transfer simulations

Midlatitude winter profile

- T_{sfc} = 272.15 K, ϵ_{sfc} = 1
- Ice crystal sizes (r_e):
  - MODIS: 7, 20, 25, and 40 μm
- Radiative transfer model
  - MODIS: DISORT

- Water drop sizes (r_e):
- MODIS: 8, 10, 16 μm

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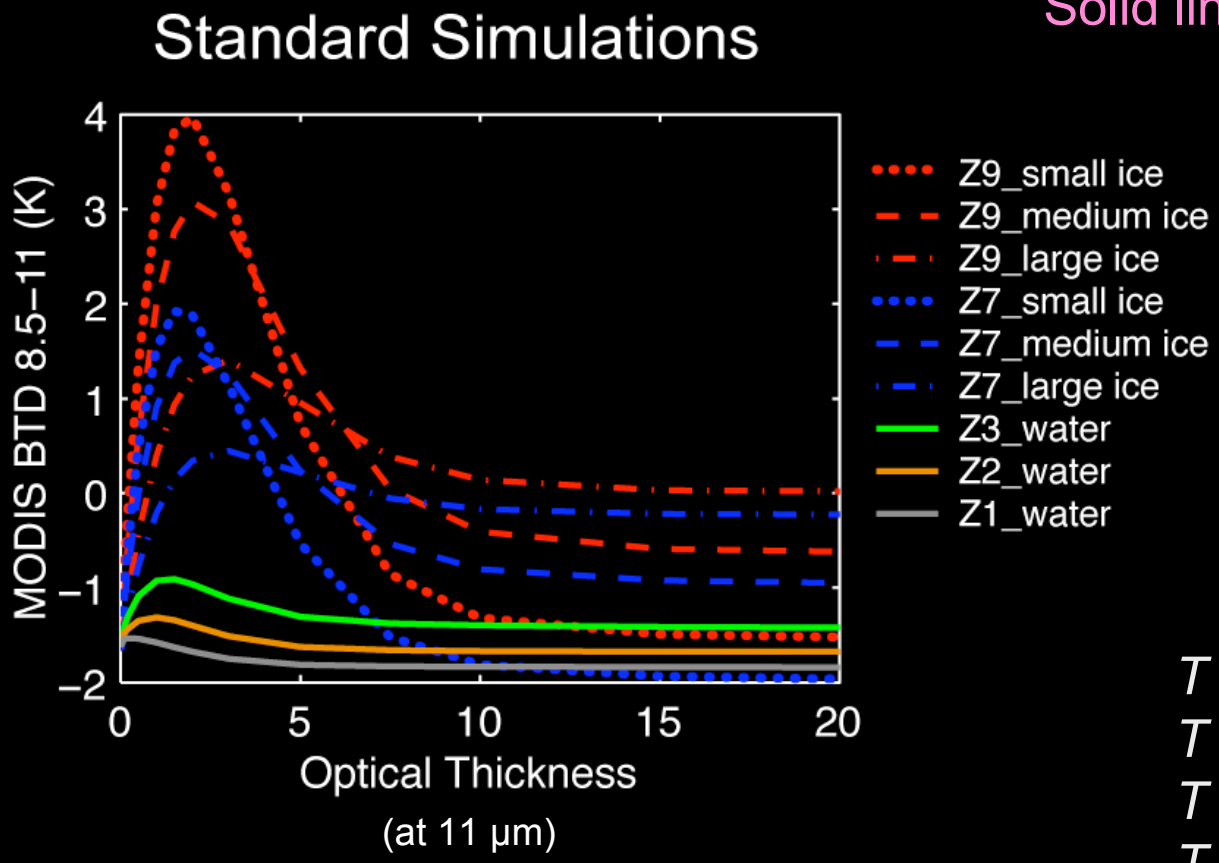
MODIS: High Ice, Low Water

Dashed lines for ice clouds
Solid lines for water clouds



T at 9 km = 226 K
T at 7 km = 238 K
T at 3 km = 262 K
T at 2 km = 265 K
T at 1 km = 269 K

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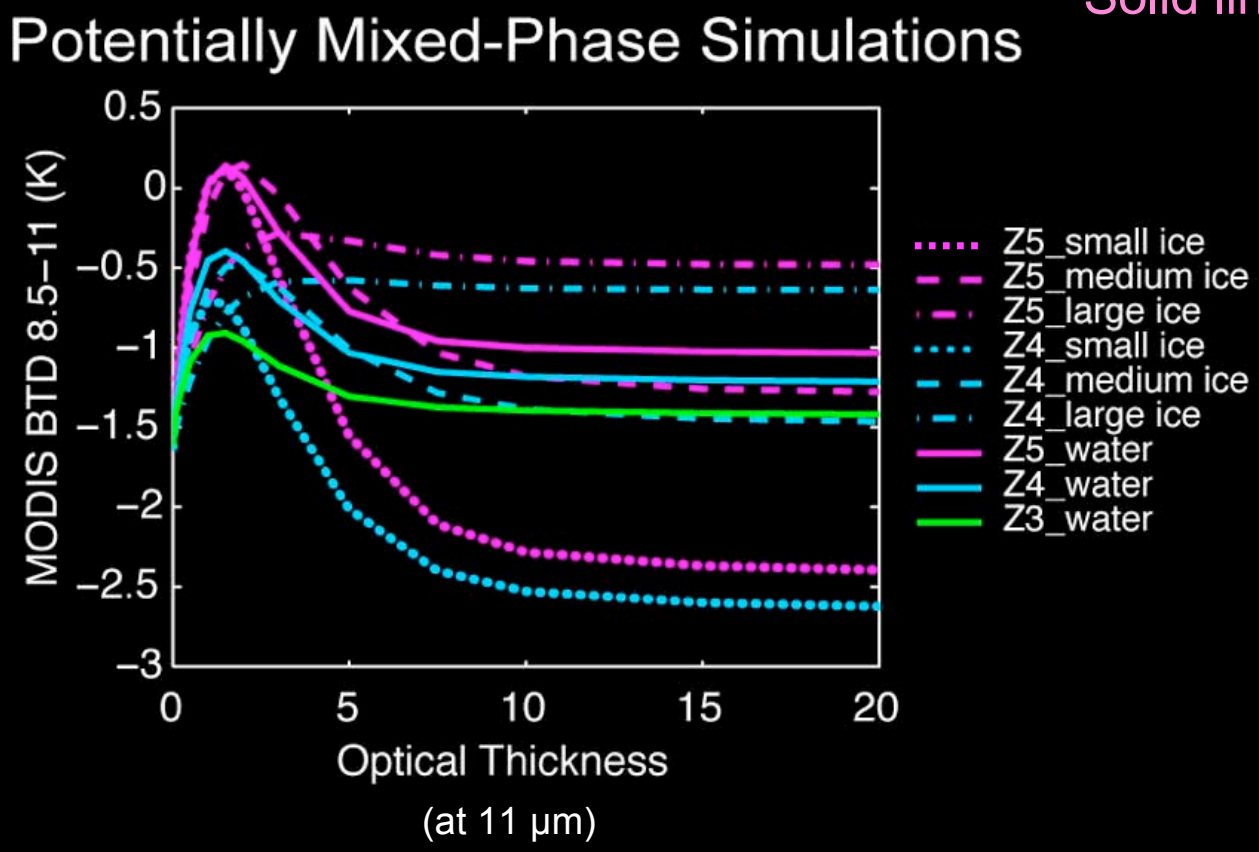
Midlevel Clouds

Dashed lines for ice clouds
Solid lines for water clouds



T at 5 km = 250 K
T at 4 km = 256 K
T at 3 km = 262 K

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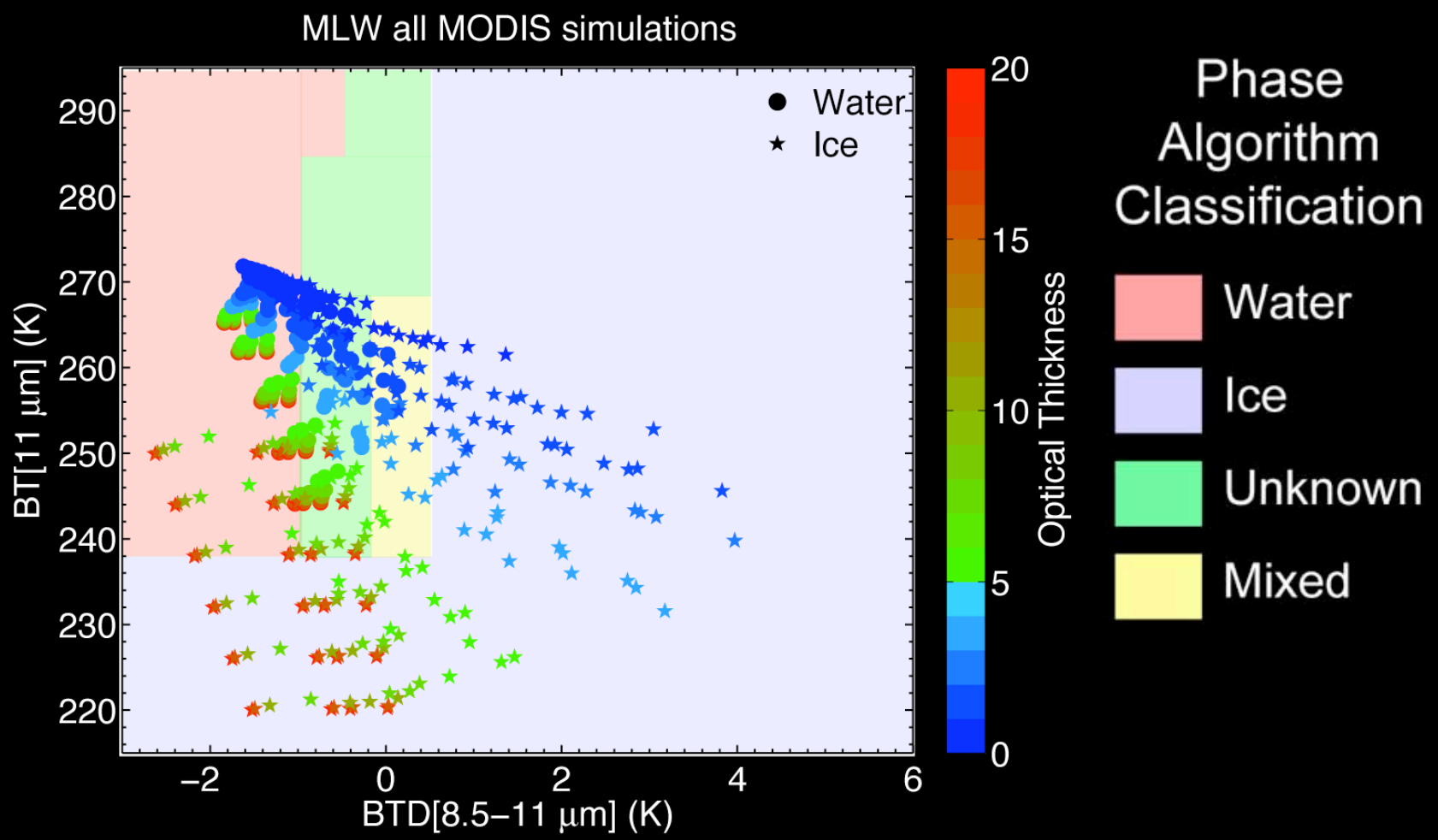
MODIS simulations: Optical Thickness



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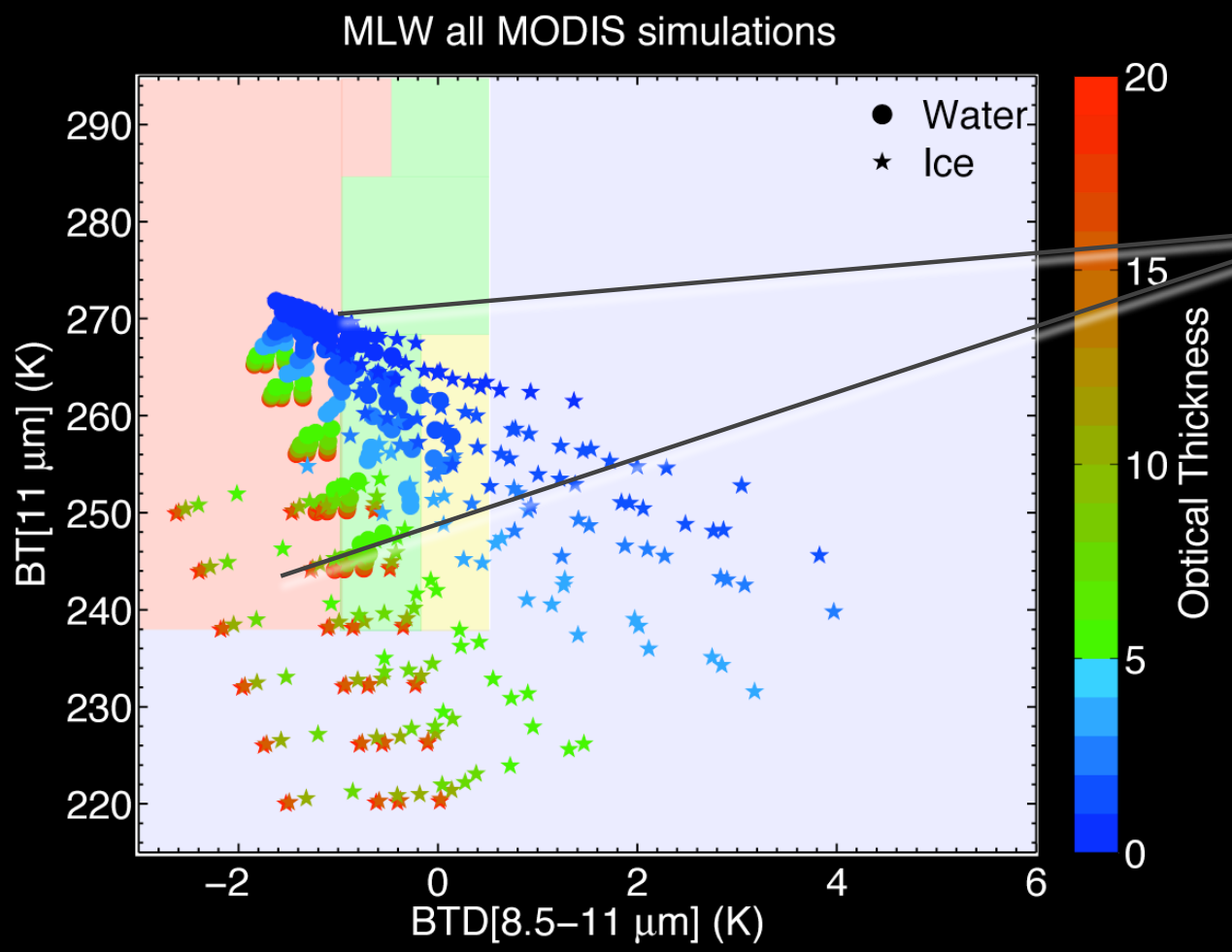

Some thin ice and thick ice clouds may be classified as water

Ice may be more likely than water to be classified as mixed or unknown

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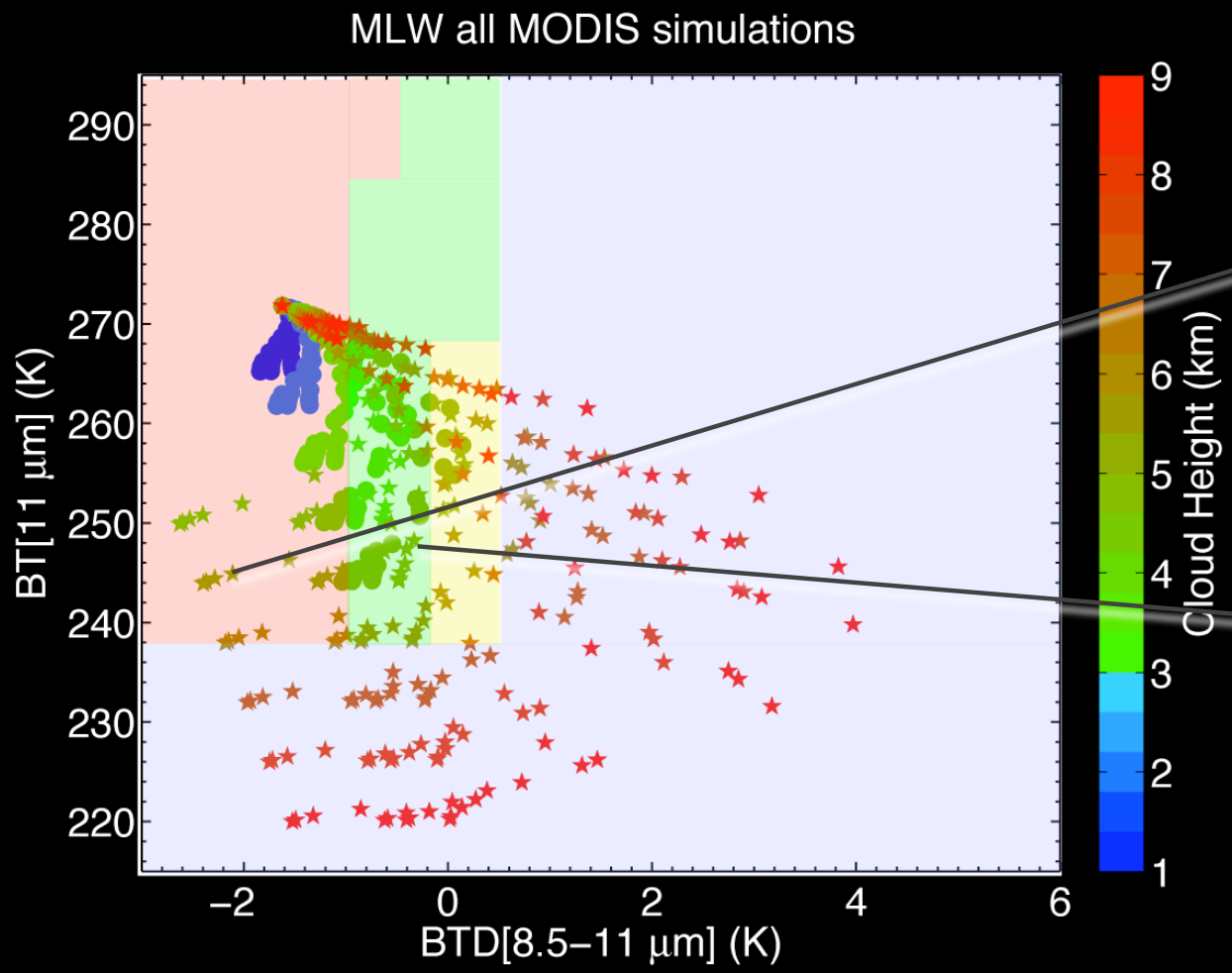
MODIS simulations: Cloud Height



"warmer" ice clouds may be classified as water

"midlevel" clouds more likely to be classified as mixed or unknown

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Can We Do Better?

- The variation of the index of refraction of water and ice over the IR window is still intriguing
- Perhaps MODIS bandwidth too broad to take advantage (recall radiance sensitivity to atmospheric emission)
- What about AIRS?

AIRS Simulations

- Same atmospheric profiles (MLW and MLS) and cloud levels as MODIS simulations
- RT calculations using CHARTS
- Different assumptions regarding ice crystal single scattering properties, but simulations are for a similar *range* of crystal sizes
- Entire AIRS spectrum modeled; results are shown for a few channels
- Channels chosen for low absorption and a range of values of index of refraction

Radiative transfer simulations

Midlatitude winter profile

- T_{sfc} = 272.15 K, ϵ_{sfc} = 1
- Ice crystal sizes (r_e):
  - MODIS: 7, 20, 25, and 40 μm
  - AIRS: 4, 6, 13, 22, 36, and 46 μm
- Radiative transfer model
  - MODIS: DISORT
  - AIRS: CHARTS

- Water drop sizes (r_e):
- MODIS: 8, 10, 16 μm
- AIRS: 8 μm
- Particle size and crystal habit distribution assumptions are different for each instrument

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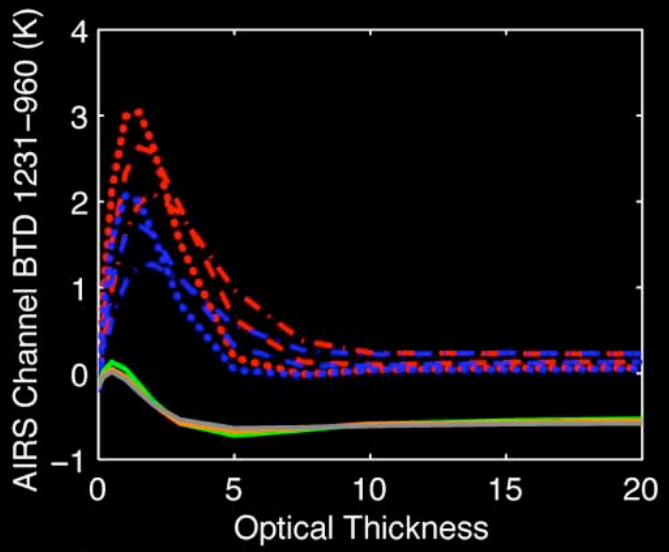
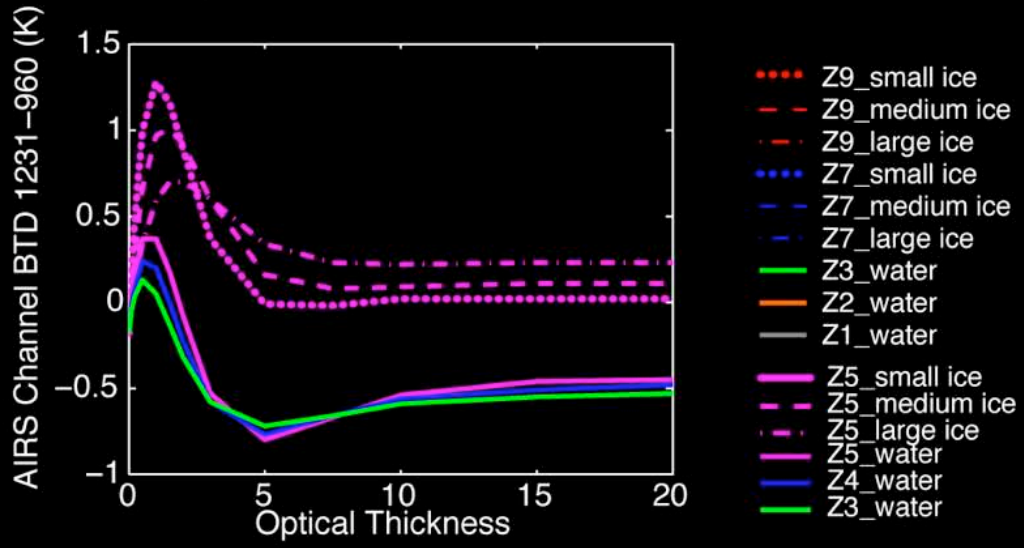
AIRS simulations show phase separation for ”easy” and “hard” cases

Cold ice, warm water



“Midlevel’ ice and water



Water cloud curves are solid, ice cloud curves are dashed or dotted.

T at 9 km = 226 K
T at 7 km = 238 K
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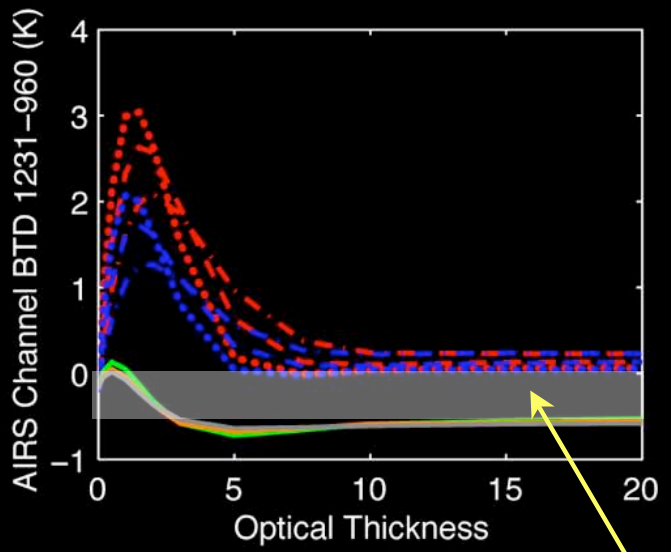

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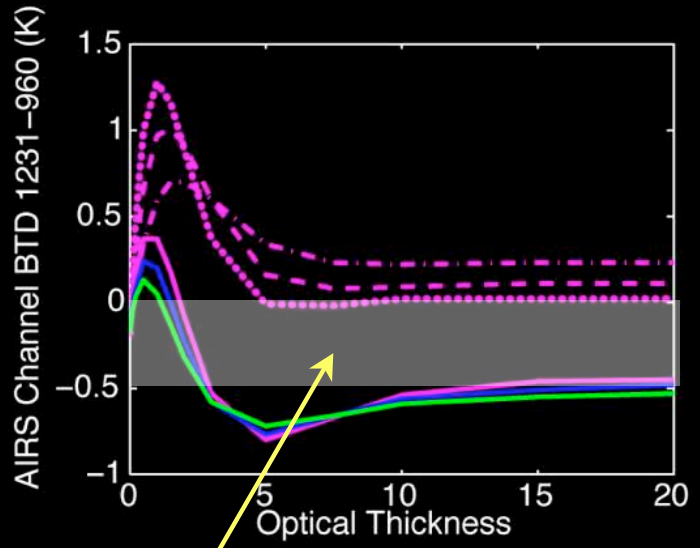

T at 5 km = 250 K
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T at 3 km = 262 K

~0.5 K phase separation

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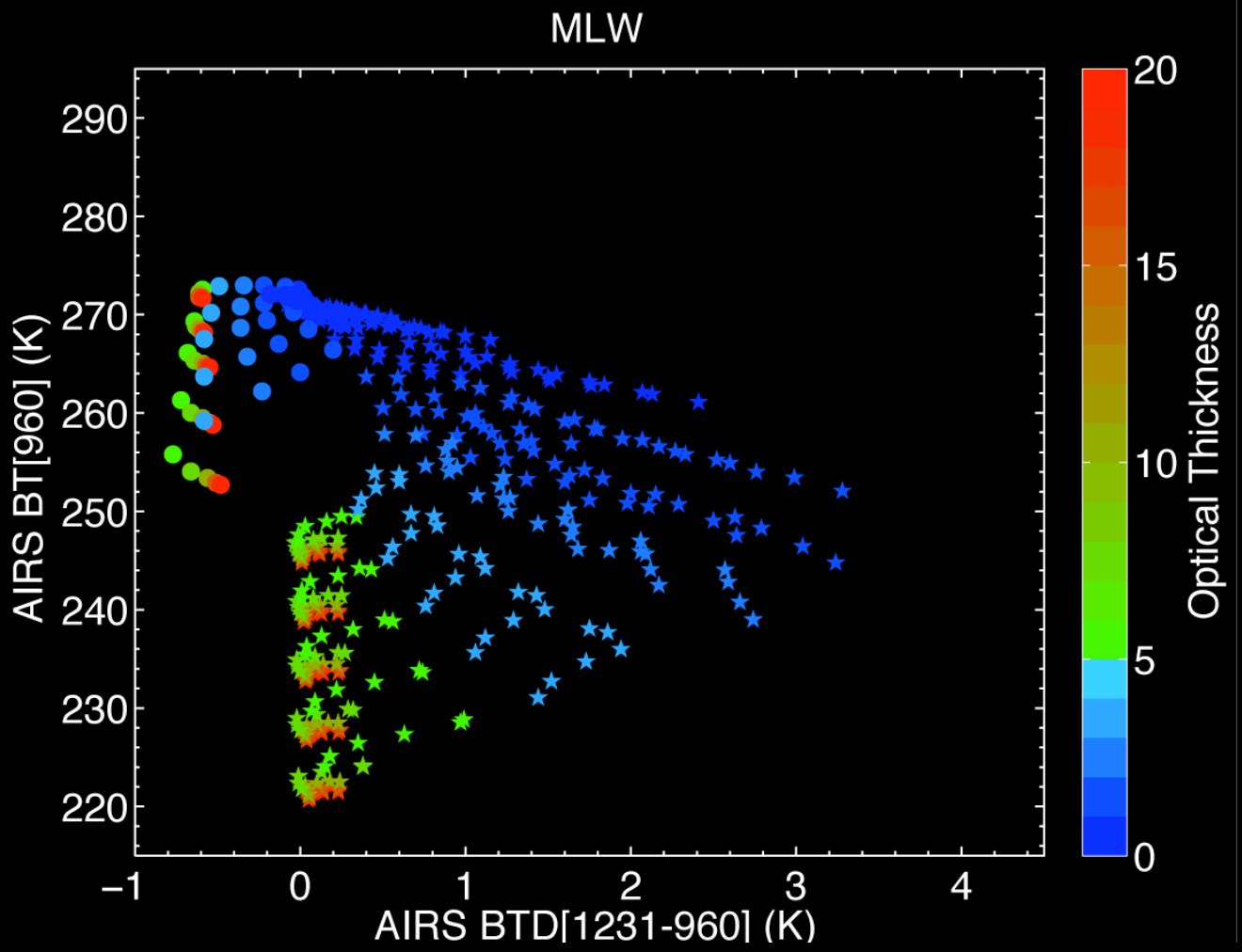
Phase Discrimination: Optical Thickness



only overlap is for thin ice and water low optical thickness

Much better phase separation

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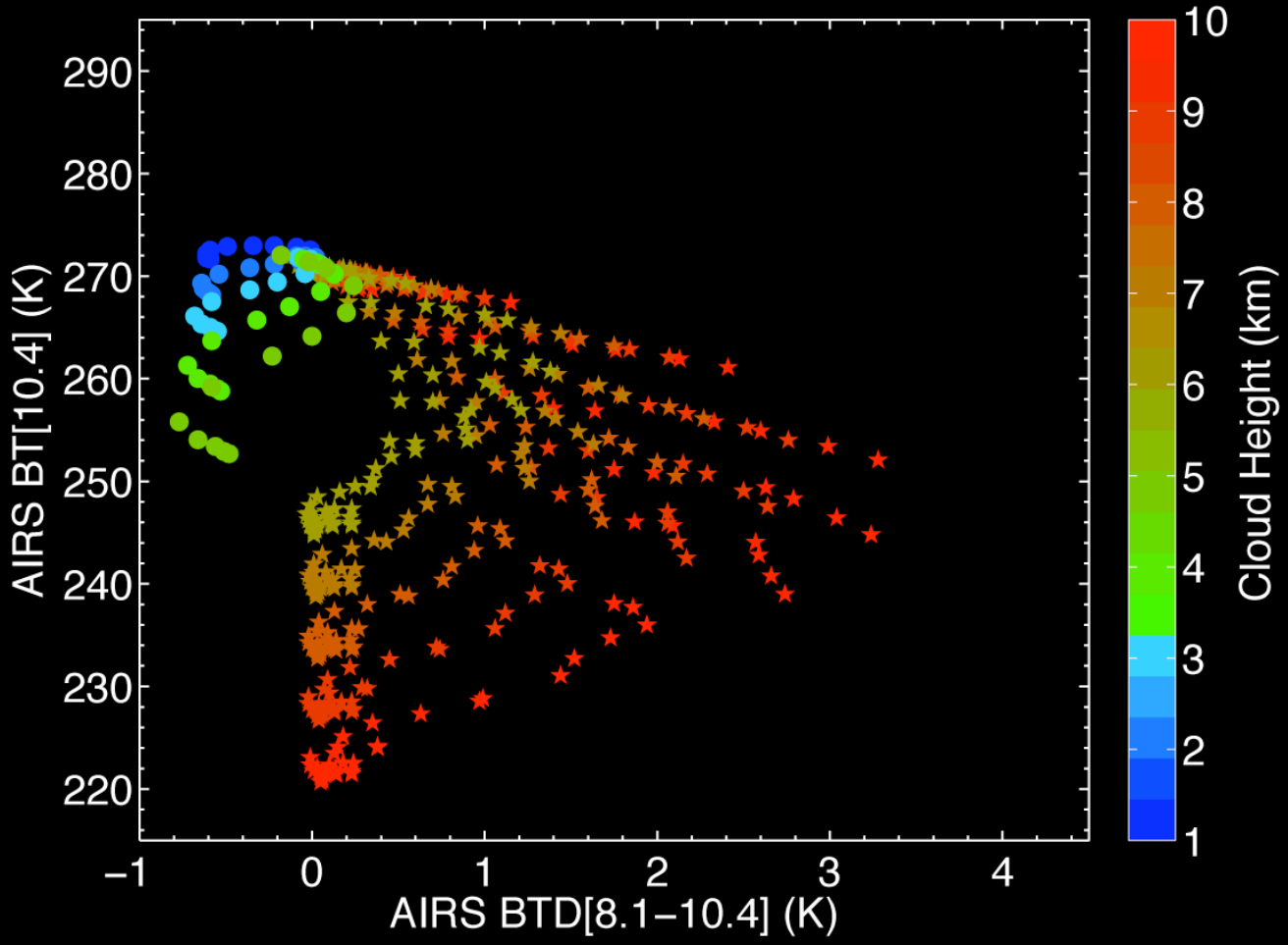
Phase Discrimination: Cloud Height



less sensitivity to cloud height than MODIS

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“Midlevel” Clouds
250 - 265 K

- Clouds with retrieved cloud top temperature between 250 and 265 are very likely to be classified as mixed or unknown by MODIS
- Within this temperature range, ice, water, and true mixed phase clouds are possible
- “Mid-level” clouds frequently fall in this range
- AIRS phase classification shows promise due to high spectral resolution
- *Nasiri and Kahn JAMC paper currently in review*

MODIS/AIRS/CALIPSO
Cloud phase case study
July 02 2007 ~0550 UTC

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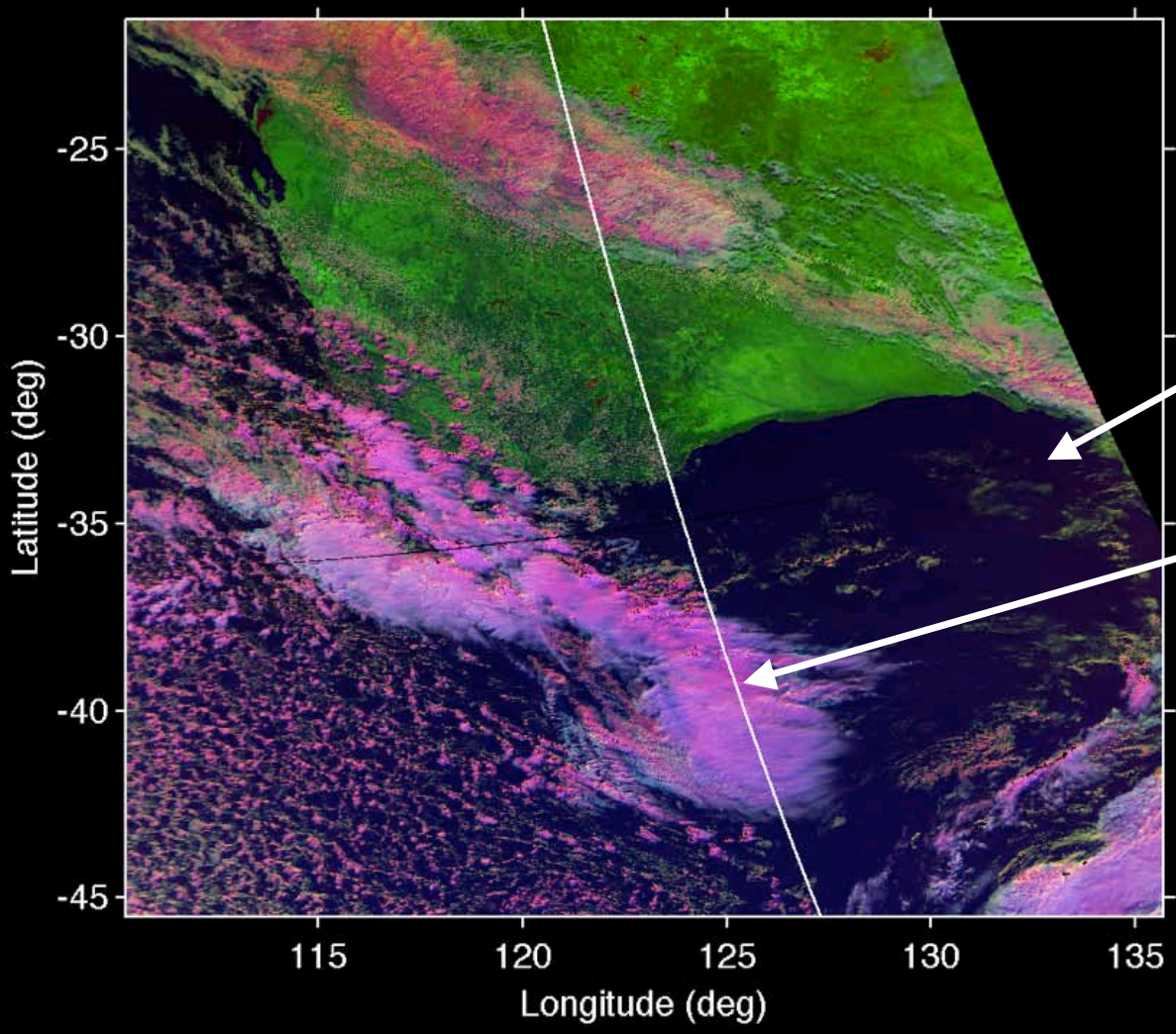
MODIS false color



July 02 2007 ~0550 UTC

Merged granules

CALIPSO Lidar Track

R = 0.65 μm reflectance
G = 2.13 μm reflectance
B = 11 μm BT (cold high)

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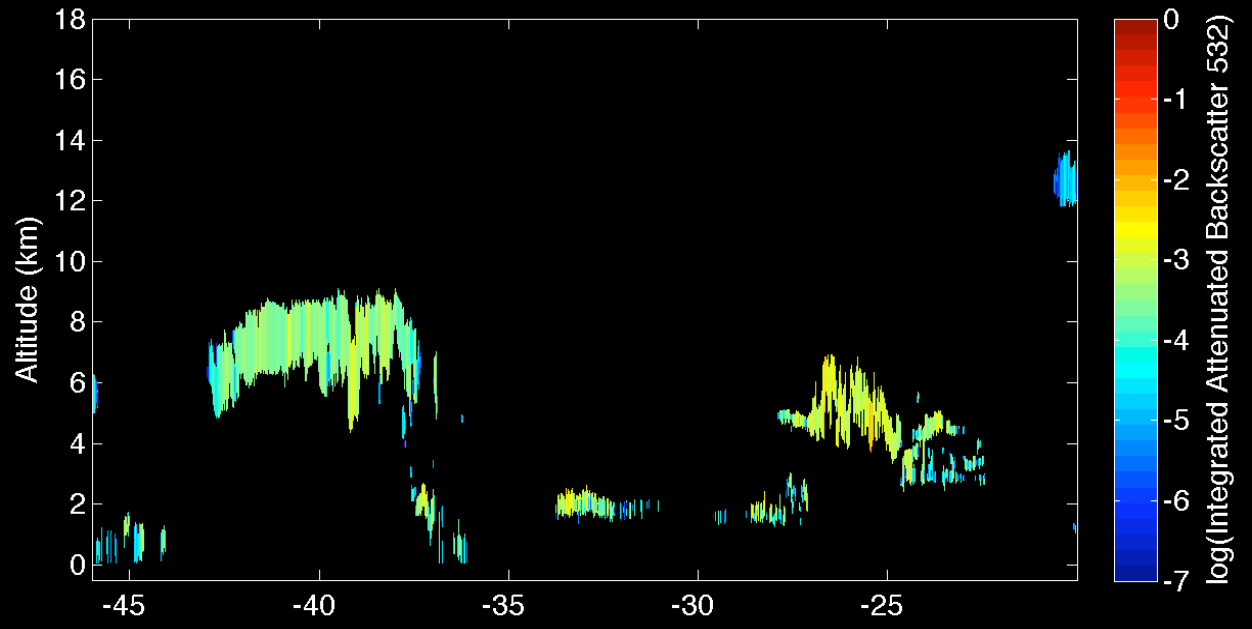
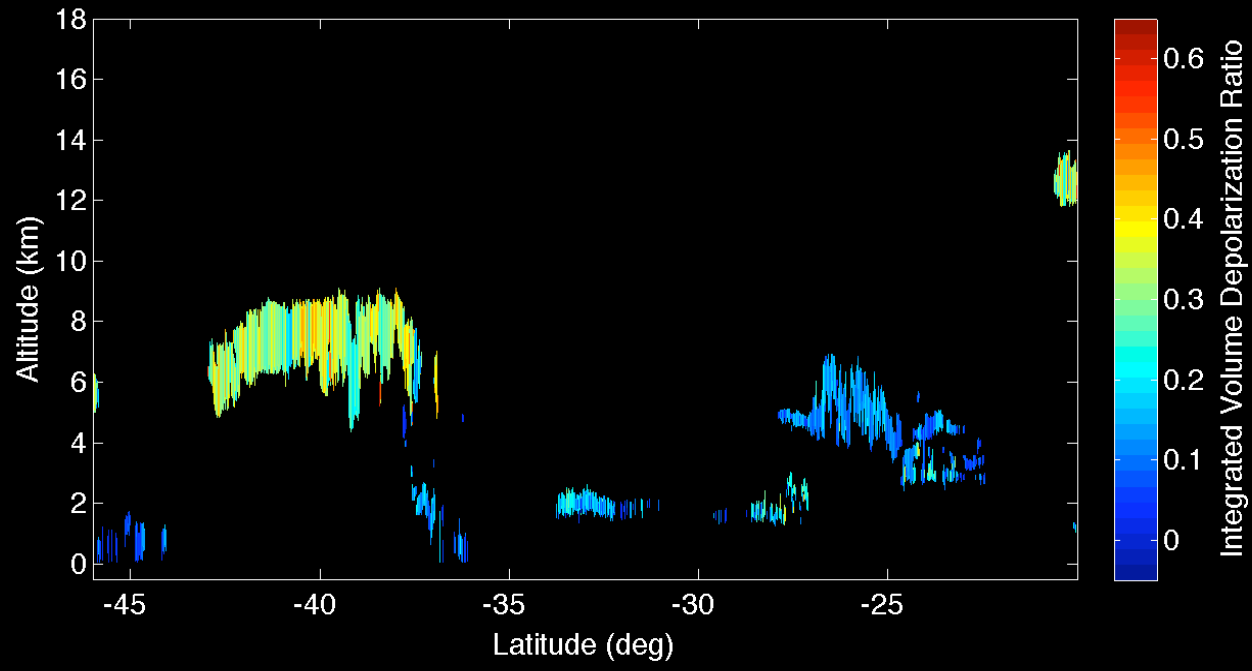
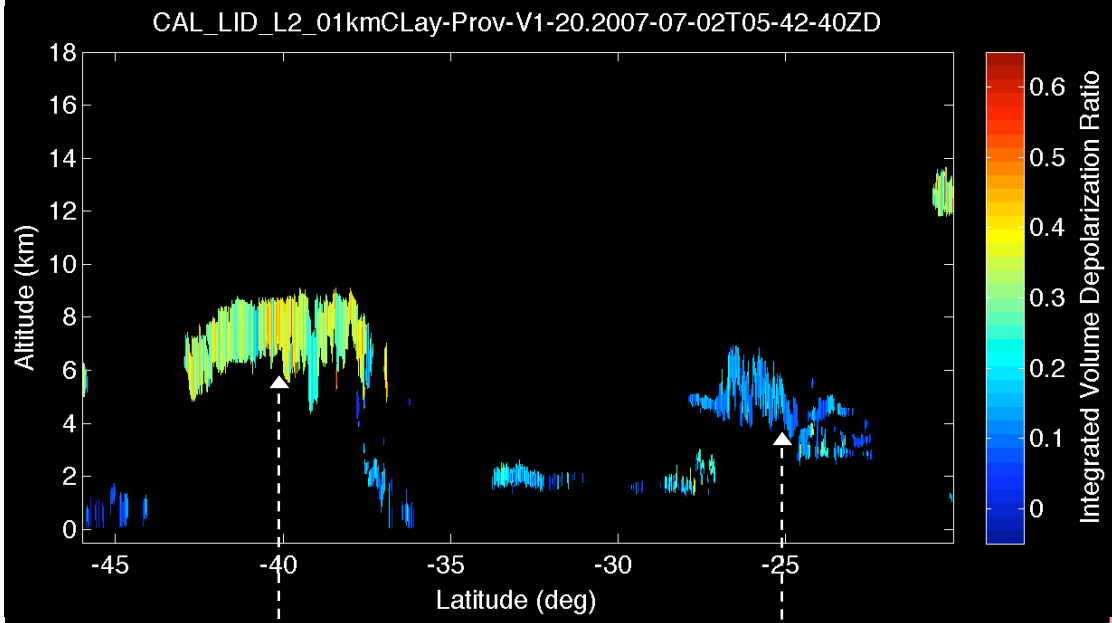


CALIPSO Integrated attenuated backscatter at 532 nm



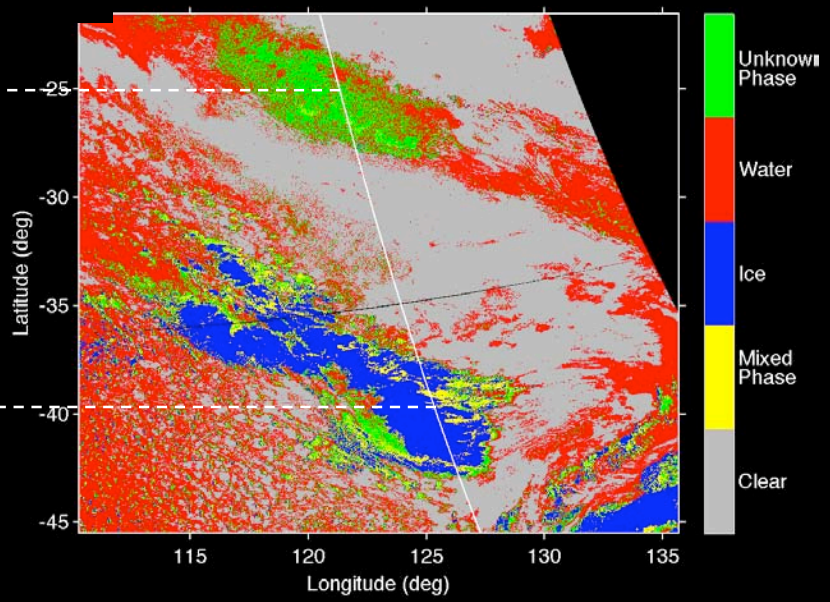
CALIPSO Integrated volume depolarization ratio

Lidar Depolarization compared to MODIS phase



CALIPSO Integrated volume depolarization ratio

MODIS 1km bispectral IR cloud phase



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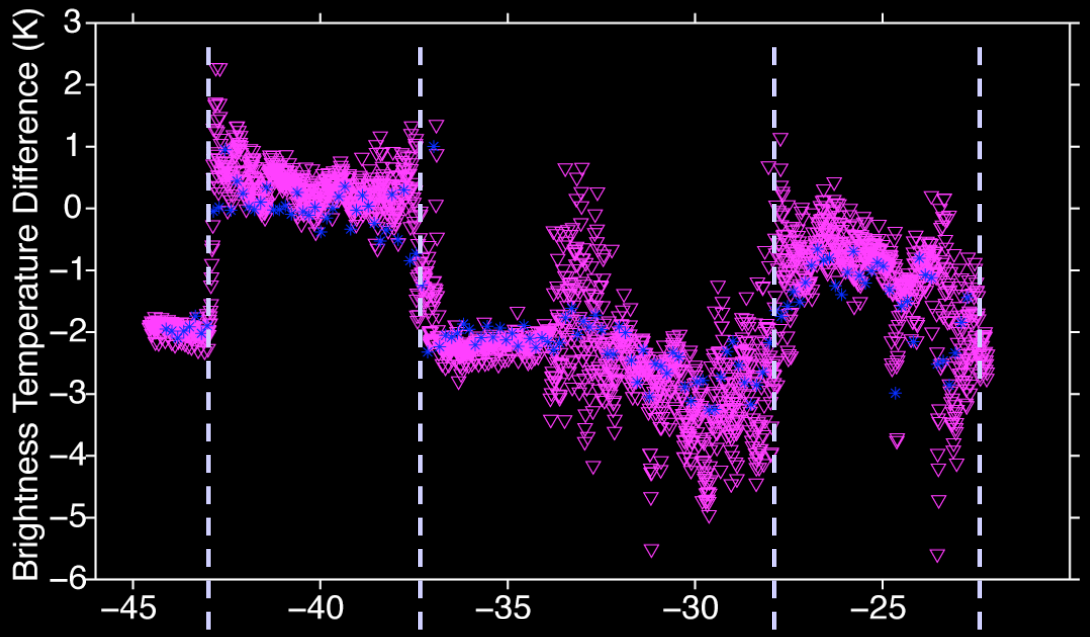
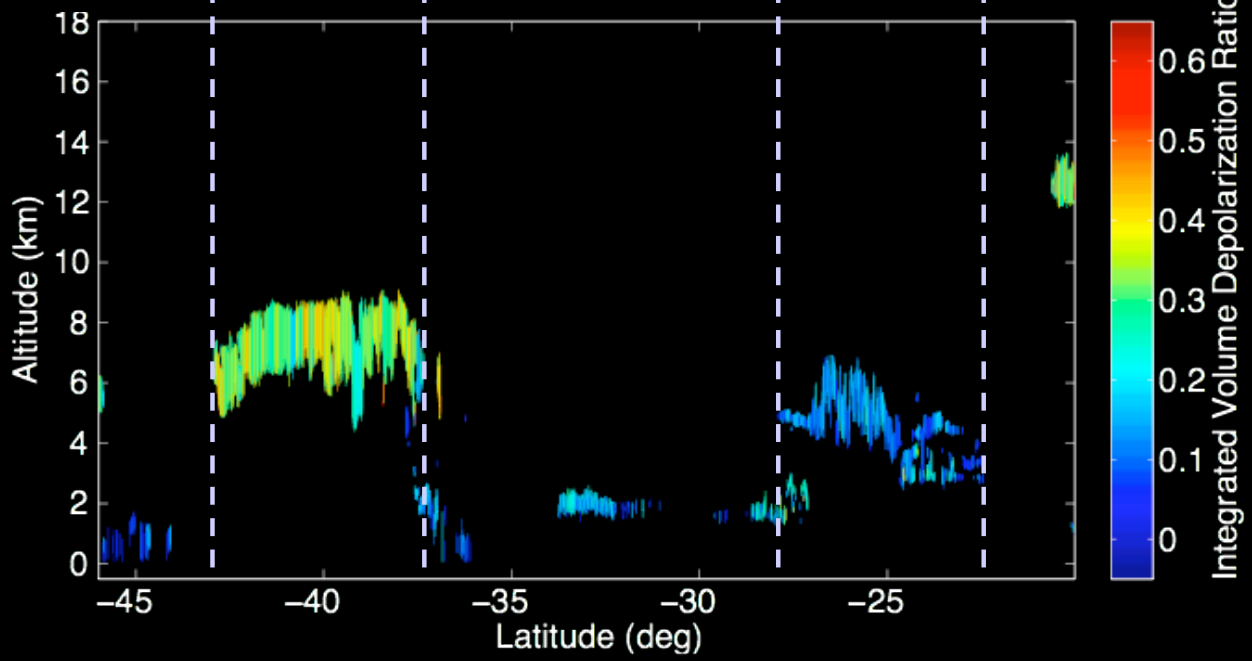
AIRS and MODIS BTDs along CALIPSO track



- AIRS BTD[1231-960 cm^{-1}]
- MODIS BTD[8.5-11 μm]



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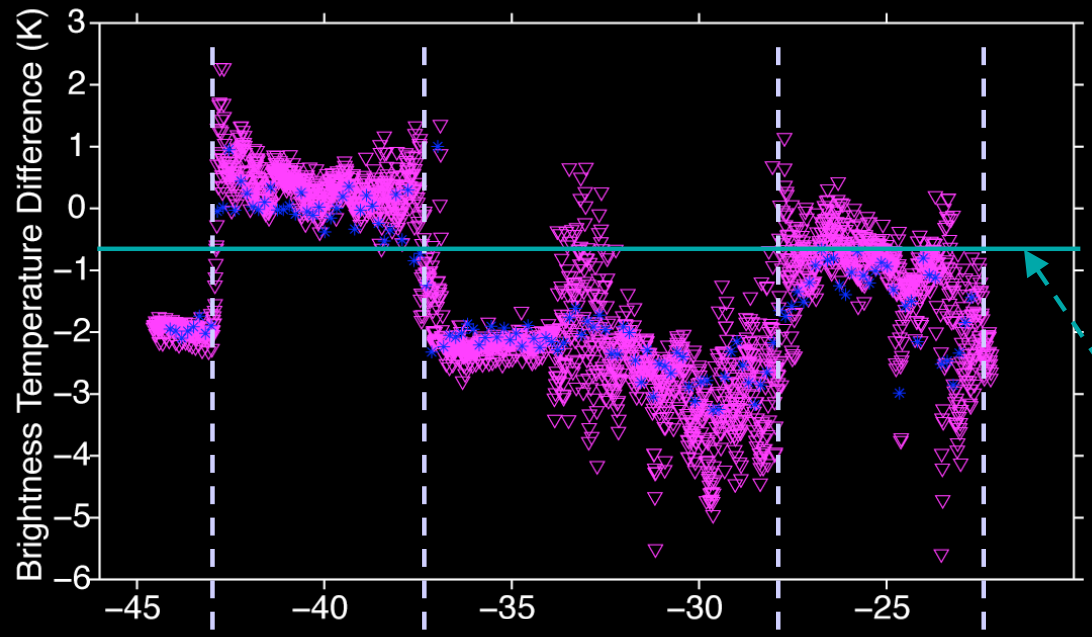
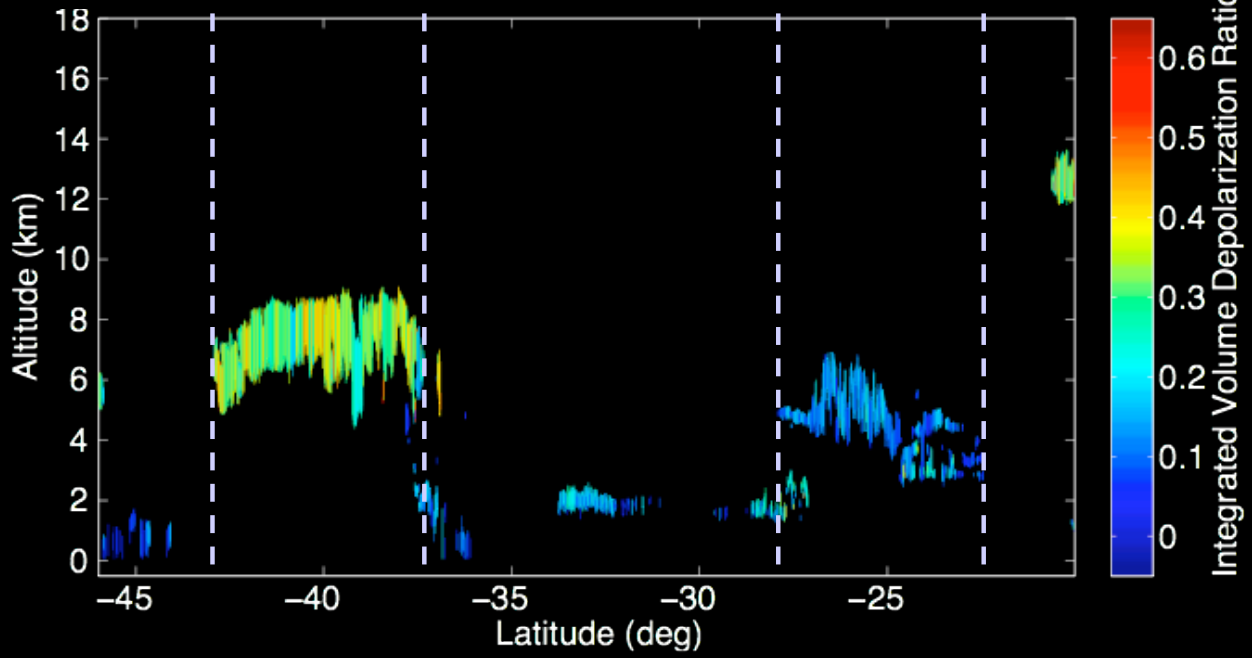


AIRS BTD[1231-960 cm^{-1}]

MODIS BTD[8.5-11 μm]



It's possible to draw a line separating ice and water clouds in the AIRS data

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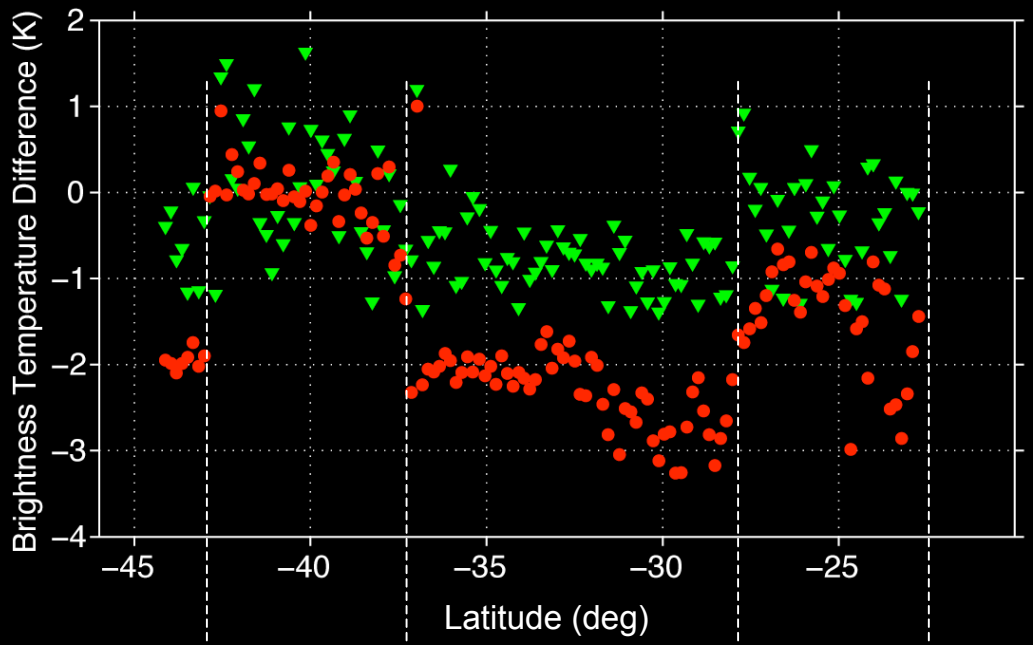
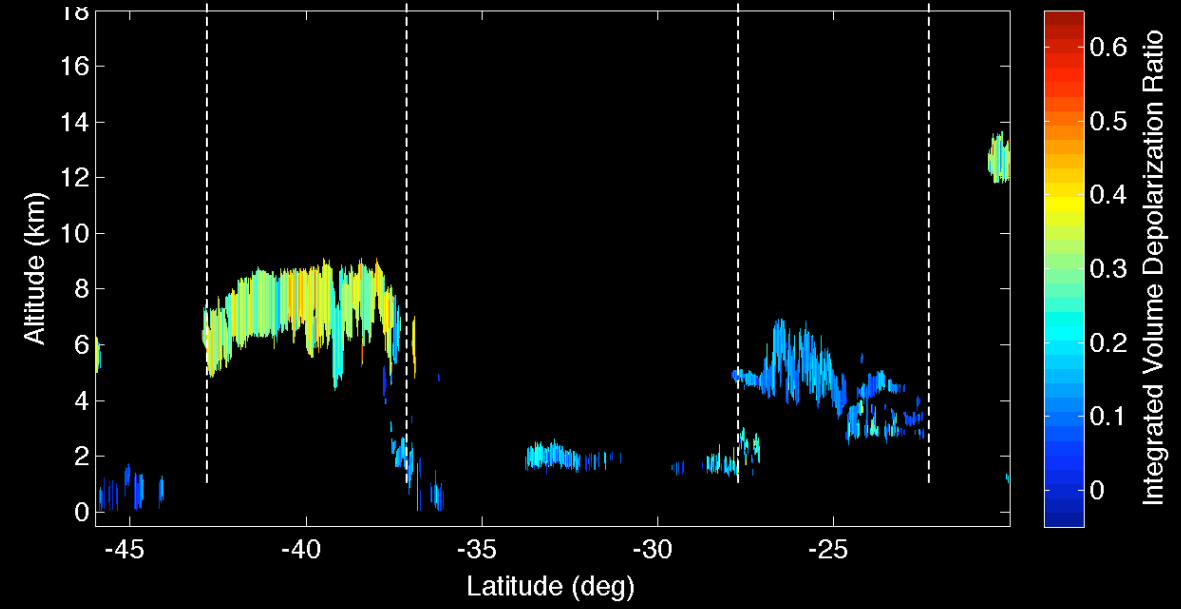
Looking for channel combinations that increase phase discrimination





- BTD[1231-960 cm^{-1}]
- BTD[926-857 cm^{-1}] – BTD[960-926 cm^{-1}]

Is AIRS the Right Instrument for Phase?

- Simulations show a 0.5 K phase separation
- Can channel combinations increase phase separation?
- What about scene variability within large AIRS footprint?
- What about true mixed-phase clouds?

Plans include testing various channel combinations for a wide variety of scenes and comparing with CALIPSO data.

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Thank you

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